JOURNAL OF AGRICULTURAL RESEARCH

VOL. XV WASHINGTON, D. C., DECEMBER 2, 1918 No. 9

EXPERIMENTS ON THE VALUE OF GREENSAND AS A SOURCE OF POTASSIUM FOR PLANT CULTURE

By RODNEY H. TRUE, *Physiologist in Charge*, and FRED W. GEISE, *Scientific Assistant, Drug-Plant, Poisonous-Plant, Physiological, and Fermentation Investigations, Bureau of Plant Industry, United States Department of Agriculture*

HISTORICAL INTRODUCTION

The practice of applying to farm lands deposits known under the broad term "marl" has a long history both in Europe and in America. Among those deposits occurring in the Atlantic coastal region from New Jersey to Virginia are the so-called "greensands" which soon after the American Revolution came into extensive use as fertilizers. These greensands were sometimes found as relatively pure glauconite, but perhaps oftener contained more or less abundant quantities of fossil shells. The lime component was frequently sufficient to give to these deposits the character of real marls.

Analyses of New Jersey greensands made by Seybert[1] in 1822 showed that iron, silica, and potash are present in pure greensand. Samples of greensand marl were found to contain in addition varying quantities of lime, phosphates, and other constituents. The value of these deposits as fertilizers was variously ascribed by different investigators to the lime, the iron, and the phosphates present. Since, however, it was not definitely determined until the early sixties that potassium is necessary for plant growth, the presence of this element could be only suspected to have connection with the valuable properties observed.

That great gains were seen in crops following the application of greensands and of greensand marls was the usual experience, and the practice of "marling" during the quiet winter months became the rule in those parts of New Jersey and Virginia in which the deposits were easy of access. This practice grew to very great proportions in a number of regions, railroads even being built in New Jersey to haul marl from pits yielding a product of high reputation out into the adjacent country.

The digging and carting of these heavy deposits, however, was a severe drain on labor, and when in the sixties concentrated soluble

[1] SEYBERT, Henry. ANALYSIS OF THE GREEN EARTH FROM RANCOCAS CREEK, NEW JERSEY. *In* Mem. Phila. Soc. Prom. Agr., v. 5, p. 21. 1826.

Journal of Agricultural Research, Washington, D. C
qk

Vol. XV, No. 9
Dec. 2, 1918
Key No. G-172

fertilizers were introduced the use of these marls quickly fell off. At the present day they are practically neglected.

DISTRIBUTION AND NATURE OF GREENSAND DEPOSITS

These deposits occur most abundantly in the Atlantic coastal plain lying on the seaward side of the "fall line," where they are oftentimes extensively exposed by the rivers which cut this line. The most important greensand deposits of the eastern States extend from Navesink Heights near Red Bank, N. J., in a southwesterly direction to a region below the James River southeast of Richmond.

The materials vary in appearance from greenish black when the greensand is fairly pure to a grayish color, which is determined by the proportion of shells and sand present. Greensand (glauconite) can usually be demonstrated as small rounded grains, black or greenish in color, present in the earth embedding the shells as a matrix and filling the hollows of the shells. The grains leave a green streak when rubbed on hard paper with a knife blade.

Especially prominent in many Virginia deposits is an overlying layer of somewhat different character, called by Edmund Ruffin "olive earth." This material, while not a greensand deposit, must be considered practically as a part of it, since it must usually be dealt with before the underlying greensand deposits can be reached. These olive earths frequently contain sufficient quantities of calcium carbonate and phosphates to give them considerable value.

CHEMICAL COMPOSITION OF GREENSAND DEPOSITS

Typical deposits from both New Jersey and Virginia were collected for this work and analyzed with special reference to the constituents generally recognized as having major importance for plant growth.[1] The materials used in the culture experiments reported below gave the results seen in Table I.

[1] Mr. Otis F. Black, Chemical Biologist, and Mr. James W. Kelly, Chemical Technician, of this Office, made the analyses.

TABLE I.—*Analyses of greensand deposits used in experiments*

Material.	Calcium oxid.	Phosphorus pentoxid.	Sulphur trioxid.	Potassium oxid.	
				Soluble in dilute hydrochloric acid.	Total potassium oxid present.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1. Greensand, Courtland, Hanover County, Va.	0.33	0.16	0.27	2.65	5.76
2. Greensand, Red Bank, Monmouth County, N. J.	1.75	.95	Trace.	6.80	7.63
3. Greensand marl, Red Bank, Monmouth County, N. J.	7.45	1.25	Absent.	6.10	6.77
4. Greensand marl, Hanover County, Va.	12.50	.17	.50	1.85	2.16
5. Greensand marl, near Tunstall, New Kent County, Va.	9.20	.33	.26	1.35	1.52
6. Greensand marl, mixture of equal parts of No. 4 and 5	10.85	.25	.38	1.60	1.84

EXPERIMENTAL METHODS

The purpose of the experimental work reported here was to ascertain whether these deposits are capable of serving as a useful source of potassium for growing plants, and if so, how promptly the potassium becomes available. It is shown clearly in the above analyses and in scores of others to be found in the extensive literature that potassium is present in greensands in considerable quantity, but earlier investigations tended to show that it is present in the form of a rather stable silicate the availability of which for plant uses has been called in question.[1]

In order to gain time and the better to control conditions of work, pot experiments were carried out in the greenhouses of the department during the past winter (1917–18). Glazed earthen pots of the ordinary 6-inch type were first used, but it was found that the glazing was usually checked by many fine cracks which reached through the surface of the glaze. The pots themselves were found to furnish soluble impurities, among them potassium compounds, in such quantities as led to the abandonment of this type of container. Common porous pots, well soaked in hot paraffin, the surplus of which was quickly drained off while still hot, gave satisfactory results. The saucers were treated in the same way.

The purest obtainable sand was used as a solid medium. A grade known as "crushed quartz" was found to be satisfactory when submitted to rather searching tests.

The best chemicals were used in making up the culture solutions.

In view of the fact that the problem was expected to give results of practical value, wheat (*Triticum aestivum*) and red clover (*Trifolium pratense*) were chosen as suitable test plants.

[1] It should always be borne in mind in considering problems of this nature that the plant's operations are not bounded by the limits which prevail in chemical-laboratory tests, and reactions that are difficult in the test tube are sometimes easily performed by the living plant.

As a source for the necessary nutrient salts a formula of culture solution worked out by Shive [1] for wheat was made use of. Since no similarly tested formula for clover culture was available, the same solution was used for the clover experiments. Shive's solution (R_5C_2) was made up on the following basis:

Potassium phosphate (KH_2PO_4).......	0.0180 mole in 1 liter of solution.
Calcium nitrate [$Ca(NO_3)_2$]...........	.0052 mole in 1 liter of solution.
Magnesium sulphate ($MgSO_4$).........	.0150 mole in 1 liter of solution.

All salts are calculated as water-free.

In this solution we should expect to have whatever mineral materials are necessary for wheat plants in proportion and concentration found by culture test to be most fitting.

To get a standard with which to compare the results obtained with the marls, a series of culture solutions was made up on the basis of Shive's solution so modified as to supply the potassium in the form of the common salts of commerce. These in very impure form have furnished a large part of the potassium present in the commercial fertilizers of the past and should give results up to which marls should measure if they are to be substituted for these salts as equally satisfactory sources of agricultural potassium.

It is well known that potassium absorption is greatest during the time when increase in volume is the predominant feature of plant development; hence, chiefly during the earlier stages of the life of the plants. The experiments, therefore, were not continued to maturity, the crop being harvested and dried for comparison after a growth period of eight weeks from the planting of the seed.

The pots, nearly filled with sand, were well watered with the desired culture solutions in case all constituents were soluble, and the seeds of wheat or red clover were immediately planted. The use of a surplus of solution was avoided in order that materials might not be washed down into the saucers and beyond the reach of the plants.

In the case of the slowly soluble greensands the quantity of material needed was weighed out and thoroughly mixed with the dry sand. These mixtures were put into the pots and irrigated with culture solutions from which all sources of potassium were omitted. It was hoped in this way to find out whether the greensand materials could yield useful potassium rapidly enough to permit the plants to make growth. Control cultures in which all nutrients but potassium were present gave a measure of the gain resulting from the presence of the salt or of the greensand. Other controls with complete culture solutions, which would be expected to yield the most favorable results were provided.

[1] SHIVE, John W. A THREE-SALT NUTRIENT SOLUTION FOR PLANTS. *In* Amer. Jour. Bot., v. 2, no. 4, p. 159. 1915. (p. 157–160.)

——— A STUDY OF PHYSIOLOGICAL BALANCE IN NUTRIENT MEDIA. *In* Physiol. Researches, v. 1, no. 7, p. 327–397, 15 fig. 1915.

RESULTS WITH POTASSIUM SALTS

Culture solutions containing potassium, whether supplied in the form of the common salts or as greensands or marls, were made up on the basis of the number of pounds of potassium supplied to a volume of soil having a surface of 1 acre and a depth of 1 foot. In the case of the slowly soluble deposits this gives a measure of direct applicability. For the salt solutions the relation is less usual, but is still a practicable way of calculating concentration. The potassium content in each case was calculated on the quantity known by analysis or formula to be present, solubility not being considered.

In Table II are given data showing the growth made by Turkey Red wheat and red clover in a series of pot sand cultures in which the potassium demand was supplied by the common salts. The concentration of potassium in each culture is given in the number of pounds applied per acre-foot. The weights of wheat tops and red-clover tops in an air-dry condition are given in other columns. The plants were harvested eight weeks after planting (see Pl. 33).

TABLE II.—*Results of the growth of wheat and red clover in quartz-sand cultures, with potassium supplied by common soluble salts*

Quartz sand plus potassium sources.	Potassium (pounds per acre).	Wheat tops (air-dry).	Red-clover tops (air-dry).
Control:		*Gm.*	*Gm.*
Culture solution (no potassium)	0.0	0.75	0.43
Shive solution complete	103.7	2.09	2.84
Potassium nitrate (KNO_3)	88.6	3.22	2.71
Do	433.2	2.62	1.75
Do	866.4	2.21	1.21
Do	1,772.8	2.10	.25
Do	2,659.3	.84	.00
Total		10.99	5.92
Potassium phosphate (KH_2PO_4)	88.6	1.95	1.80
Do	433.2	1.37	1.88
Do	866.4	1.44	.80
Do	1,772.8	.92	.20
Do	2,659.3	.25	.00
Total		5.93	4.68
Potassium chlorid (KCl)	88.6	1.35	1.00
Do	433.2	1.35	.59
Do	866.4	1.65	.69
Do	1,772.8	1.20	.63
Do	2,659.3	.97	.32
Total		6.52	3.23
Potassium sulphate (K_2SO_4)	88.6	1.10	.66
Do	433.2	1.53	.70
Do	866.4	1.36	1.03
Do	1,772.8	1.17	.50
Do	2,659.3	.95	.05
Total		6.11	2.94

In the control solutions, a rough idea of the growth that can be made on the reserve potassium stored in the seeds is shown in the first line, in which sand and a nutrient solution containing no potassium were present. In the second line the development made in the complete Shive culture solution gives what should be a maximum result. It is but fair to point out that in working out this formula Shive used wheat, for which it was the most favorable combination he obtained. It is quite possible that red clover might prosper better in a somewhat different combination. Since, however, no carefully worked out data, such as Shive has given for wheat, were known for clover, it was decided to use the same solution for both plants in the belief that this same solution would be favorable, though perhaps not the most favorable that might be found.

As a general outstanding feature of this series it will be noted that growth decreases as concentration increases. This seems to indicate that the concentrations lie between the maximum and the toxic, contrasting sharply, as will be seen, with the slowly soluble marls and greensands. A number of cases seem to call for comment.

For both the potassium-nitrate and potassium-phosphate series it seems likely that the minimum concentration of 88.6 pounds of potassium per acre is the most favorable one offered for wheat, the increase in quantity of salt being accompanied by a decreasing growth. In the case of the clover 433.2 pounds of potassium, offered as potassium phosphate, is a little more favorable than 88.6 pounds, indicating that neither of these quantities is injuriously high.

It may be noted that in all nitrate cultures except the most concentrated the growth of the Shive control is equaled or exceeded, whereas in no clover culture was the control quite equaled.

In the case of potassium chlorid and potassium sulphate a somewhat different result appears. In no culture with either wheat or clover containing either salt was the growth made in the Shive control equaled. A further point of interest lies in the fact that the maximum growth of wheat was found in higher concentrations, 866.4 pounds of potassium in potassium chlorid and 433.2 pounds in potassium sulphate, indicating that the most favorable concentration lies somewhere in the range here covered and that reduced growth in the less concentrated members of the series is not due to harmful concentration of salts. In the case of the clover the best result with potassium chlorid is seen in the greatest dilution, and a more favorable result still might have been gained had a still smaller quantity of this salt been used. In the case of potassium sulphate the best result is seen in higher concentration, 866.4 pounds per acre.

Since the two latter salts have a greater commercial significance in connection with the commercial potassium supply, it is of especial importance to note the results following their use.

It is clear that potassium nitrate is able to supply something that gives this salt an advantage clearly not derived from the potassium content solely. It is probable that the nitrate ion contributed a favorable action lacking to the other potassium salts used.

As a practical means of meeting the potassium need this could hardly be considered a practicable resource under present conditions.

RESULTS WITH GREENSANDS AND GREENSAND MARLS

A chemical study of the composition of greensand deposits shows a wide variation not only in the materials present but likewise presents almost every possible combination in proportions present. While potassium, silica, and iron are ever-present constituents of glauconite, with it are oftentimes found sulphates and phosphates, the latter sometimes in considerable quantity. Calcium, usually present, is, of course, a major constituent in the marl types.

It is obviously difficult to get a strict basis of comparison between these complex mixtures of slowly-soluble materials and the readily-soluble pure salts above reported. It was hoped, however, that this might be done by supplying in the culture solutions with which the pots containing these sand and marl mixtures were watered sufficient phosphates and sulphates to supply the necessary demand of the rather sparse plantings made in the pots. Such necessary constituents present in quantities sure to be sufficient to satisfy the demands of the plants would tend to reduce or efface the influence of additional quantities of these substances added in the marls. The only required constituent not present in the basic culture solution would be potassium, which would of necessity be drawn by the plants from the marls or greensand, if they were to get them anywhere.

After deposits from several regions, chiefly from Virginia and New Jersey, had been collected and analyzed, certain typical deposits from both States were selected for use in these experiments. Two samples called "greensand," because of the low lime content were selected, one from each State. Two samples of "greensand marl," containing from 7.45 to 12.50 per cent of calcium oxid were also used, one from New Jersey and a mixture of equal parts of two from Virginia. All are low in phosphates and sulphates and vary widely in their potassium content.

In making up the cultures in the manner already described, the quantities of marl taken cover the rates of application customary in the days of "marling." The potassium present was calculated, not on the more readily available portion extracted with dilute hydrochloric acid but on the total potassium present, determined by the hydrofluoric- acid method.[1]

[1] HICKS, William B., and BAILEY, Reginald K. METHODS OF ANALYSIS OF GREENSAND. *In* U. S. Geol. Survey Bul. 660-B, p. 53. 1917.

In Table III appear the results obtained with wheat and red clover recorded as in Table I (see Pl. 34).

TABLE III.—*Results of the growth of wheat and red clover in quartz-sand cultures, with potassium supplied by greensand and greensand marls*

Quartz sand plus potassium sources.	Potassium in pounds per acre.	Wheat tops (air dry).	Red clover tops (air dry).
		Gm.	*Gm.*
Culture solution (no potassium)	0.0	0.75	0.43
Shive solution complete	103.7	2.09	2.84
Courtland, Va., greensand:			
1 ton per acre-foot	88.6	1.23	.85
5 tons per acre-foot	433.2	1.14	.68
10 tons per acre-foot	866.4	.40	.24
20 tons per acre-foot	1,772.8	.22	Dead.
30 tons per acre-foot	2,659.3	.21	Dead.
Total		3.20	1.77
Pamunkey Valley, Va., shell marl:			
1 ton per acre-foot	30.5	1.33	1.10
5 tons per acre-foot	152.5	1.79	1.37
10 tons per acre-foot	305.0	1.78	2.05
20 tons per acre-foot	610.0	1.95	1.82
30 tons per acre-foot	915.0	2.12	1.87
Total		8.97	8.21
Control (no potassium)	.0	.96	.47
Shive solution complete	103.7	1.98	1.49
Red Bank, N. J., greensand, lower layer:			
1 ton per acre-foot	126.6	1.59	1.10
5 tons per acre-foot	633.0	1.95	2.60
10 tons per acre-foot	1,266.0	2.00	1.90
20 tons per acre-foot	2,532.0	2.27	1.60
30 tons per acre-foot	3,798.0	2.02	1.52
Total		10.83	8.72
Red Bank, N. J., marl, upper layer:			
1 ton per acre-foot	112.3	1.00	.82
5 tons per acre-foot	561.0	1.62	1.36
10 tons per acre-foot	1,123.0	1.96	1.87
20 tons per acre-foot	2,246.0	1.89	1.67
30 tons per acre-foot	3,369.0	2.07	2.10
Total		8.54	9.82

The work reported in Table III was carried out in two series, the Courtland greensand and Pamunkey shell marl with their controls, preceding the experiment with the two Red Bank deposits and their controls. It is believed, however, that all may be compared, since the surrounding conditions were subject to no significant variation.

It will be noted that, owing to the widely varying potassium content of these deposits, the same tonnage applied gave widely different quanti-

ties of potassium. These values are indicated as before in terms of pounds of potassium per acre-foot.

On recalling the experiments with potassium-containing salts (Table II), it will be remembered that the greatest weight of tops was usually seen in the weaker solutions, falling off as the concentration was increased. This was regarded as being due to the harmful action of the excess salts.

Here the case is in general the opposite, the weight of tops increasing as the quantity of marl or of greensand increases. This may be interpreted as being due to the increasing quantity of potassium obtained by the plants from the greater surface of the potassium-yielding particles. It seems probable that in all cases except in that of the Courtland greensand the potassium demand is fully satisfied in the cultures containing the maximum quantity of both greensand and marl, in all three cases the plants approaching or exceeding in growth the corresponding control in Shive's complete solution.

It will be further noted that even where smaller doses of marl are used (1 to 5 tons per acre-foot) the yield often exceeds the result obtained with potassium salts in their most favorable concentration. Thus the poorest yield with Red Bank greensand (1.59 gm. of tops with an application of 1 ton per acre-foot, containing 126 pounds of potassium) exceeds the yield obtained with potassium sulphate (1.53 gm. with 433.2 pounds of the potassium per acre-foot), and almost equals the best yield with potassium chlorid (1.65 gm. with 866.4 pounds per acre-foot).

In all cases (Courtland greensand excluded) the best results with marls and greensands exceed the best results with potassium salts (potassium nitrate excepted).

A comparison of the total growths made in each series of cultures helps to give an idea of the value of each material in the quantities here used. Such a summary is given in Table IV.

TABLE IV.—*Total weights of wheat and red clover in potassium salts and greensand marl*

Material.	Potassium salts—Air-dry tops.		Material.	Greensand marl—Air-dry tops.	
	Wheat.	Red clover.		Wheat.	Red clover.
	Gm.	*Gm.*		*Gm.*	*Gm.*
Potassium nitrate	10. 99	5. 92	Courtland, Va., greensand	3. 60	1. 77
Potassium phosphate	5. 93	4. 68	Red Bank, N. J., greensand	10. 83	8. 72
Potassium chlorid	6. 52	3. 23	Pamunkey Valley, Va., marl	8. 97	8. 21
Potassium sulphate	6. 11	2. 94	Red Bank, N. J., marl	8. 54	9. 82

While the growth made in cultures in which the potassium demand is satisfied by greensand deposits (the poisonous Courtland greensand excepted) is markedly superior to that contained in cultures containing the commoner potassium salts (potassium nitrate excepted), it must be remembered that in the case of the salts a majority of the cultures contain an excess of salts, whereas in the marl and greensand cultures the concentration rarely exceeds the optimum and probably still less often attains it.

Concerning Courtland greensand, so often excepted in the above discussion, it may be said that this deposit has been found to belong to the unusual class of so-called "poisonous marls." Since this is a very unusual case and one not likely to be often encountered, it is sufficient to say that ground limestone added at the rate of a ton or more to the acre seems likely to render this greensand a useful fertilizer when applied at the rate of 1 to 5 tons per acre.

CONCLUSIONS

It has been shown by pot experiments carried out with crushed quartz and Shive's culture solution as a basis that greensands and greensand marls from Virginia and New Jersey are able to supply sufficient potassium to satisfy the demand of Turkey Red wheat and red clover during the first two months of their growth. This enables them to make a greater dry weight of tops than was seen in similar cultures in which the potassium demand was supplied by potassium chlorid, potassium sulphate, and potassium phosphate. The prompt availability of sufficient potassium to meet the needs of many, perhaps most, farm crops seems to be indicated.

PLATE 33

Sand cultures with potassium salts:

A.—I, Turkey Red wheat. Potassium supplied in potassium nitrate.
- 1, Control in culture solution containing no potassium.
- 2, Control culture in complete Shive solution (R_3C_2).
- 3, Culture solution, 88.6 pounds of potassium per acre.
- 4, Culture solution, 433.2 pounds of potassium per acre.
- 5, Culture solution, 866.4 pounds of potassium per acre.
- 6, Culture solution, 1,772.8 pounds of potassium per acre.
- 7, Culture solution, 2,659.3 pounds of potassium per acre.

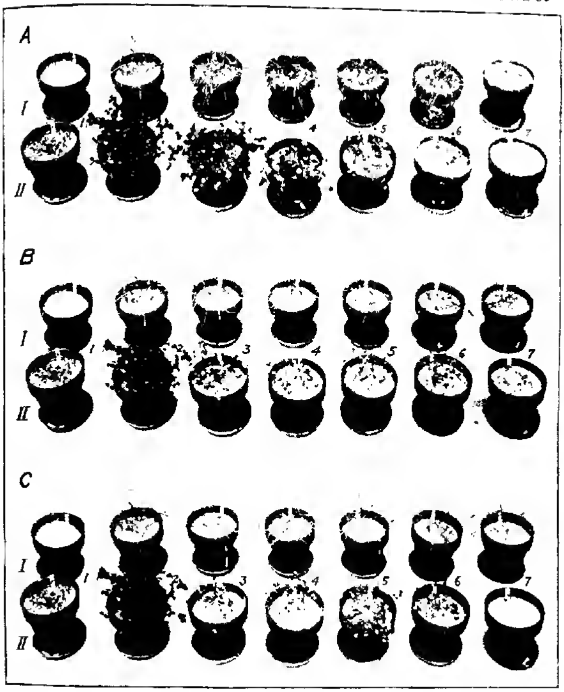
II, Red clover. Potassium supplied in potassium nitrate. Individual cultures as above indicated.

B.— I, Turkey Red wheat. Potassium supplied in potassium chlorid. Individual cultures as above indicated.

II, Red clover. Potassium supplied in potassium chlorid. Individual cultures as above indicated.

C.— I, Turkey Red wheat. Potassium supplied in potassium sulphate.

II, Red clover. Potassium supplied in potassium sulphate. Individual cultures as above indicated.


A
B
C

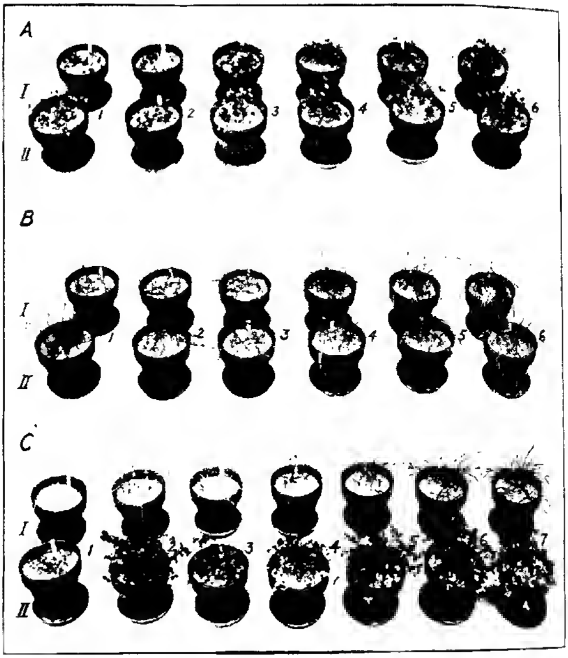

A
I
II
1
2
3
4
5
6
B
I
II
1
2
3
4
5
6
C
I
II
1
2
3
4
5
6
7

PLATE 34

Cultures with greensand deposits:

A.—Red clover. Potassium supplied in greensand deposits from Red Bank, N. J.

I, Series with greensand marl from upper stratum.

II, Series with greensand from lower stratum.

I—1, Control culture solution containing no potassium.

II—1, Control culture. Complete Shive solution (R_5C_2).

I—2, Culture solution lacking potassium, plus 1 ton of greensand marl per acre-foot.

II—2, Culture solution lacking potassium, plus 1 ton of greensand per acre-foot.

I—3, Culture solution lacking potassium, plus 5 tons of greensand marl per acre-foot.

II—3, Culture solution lacking potassium, plus 5 tons of greensand per acre-foot.

I—4, Culture solution lacking potassium, plus 10 tons of greensand marl per acre-foot.

II—4, Culture solution lacking potassium, plus 20 tons of greensand per acre-foot.

I—5, Culture solution lacking potassium, plus 20 tons of greensand marl per acre-foot.

II—5, Culture solution lacking potassium, plus 20 tons of greensand per acre-foot.

I—6, Culture solution lacking potassium, plus 30 tons of greensand marl per acre-foot.

II—6, Culture solution lacking potassium, plus 30 tons of greensand per acre-foot.

B.—Turkey Red wheat. Potassium supplied in greensand deposits from Red Bank, N. J. Designations of series and of individual cultures as above.

C.— I, Turkey Red wheat. Potassium supplied in greensand marl from Pamunkey Valley, Va.

1, Control. Culture solution containing no potassium.

2, Shive solution, complete.

3, Culture solution lacking potassium, plus 1 ton of greensand marl per acre-foot.

4, Culture solution lacking potassium, plus 5 tons of greensand marl per acre-foot.

5, Culture solution lacking potassium, plus 10 tons of greensand marl per acre-foot.

6, Culture solution lacking potassium, plus 20 tons of greensand marl per acre-foot.

7, Culture solution lacking potassium, plus 30 tons of greensand marl per acre-foot.

II, Red clover. Potassium supplied in greensand marl from Pamunkey Valley, Va. Designations of individual cultures as in C–I.

EFFECT OF FARM MANURE IN STIMULATING THE YIELDS OF IRRIGATED FIELD CROPS

By C. S. Scofield

Agriculturist in Charge, Western Irrigation Agriculture, Bureau of Plant Industry, United States Department of Agriculture

LOCATION OF THE EXPERIMENTS

The experiments reported in this paper were conducted at three field stations operated by the Bureau of Plant Industry. These stations are all located in the northern Great Plains and fairly represent conditions in that portion of the area lying in the eastern parts of Wyoming and Montana and in the western parts of Nebraska and South Dakota.

The three stations are as follows: (1) The Scottsbluff Station,[1] located on the North Platte Reclamation Project, north of Scottsbluff and east of Mitchell, Nebr.; (2) the Belle Fourche Station, located on the Belle Fourche Reclamation Project, about 30 miles east of Belle Fourche, near the town of Newell, S. Dak.; (3) the Huntley Station,[2] located on the Huntley Reclamation Project about 20 miles east of Billings, near the town of Huntley, Mont.

Each of these stations represents a large section of irrigated land, not only that included within the limits of individual reclamation projects but even more extended areas which are adjacent in the same drainage basins. The climate of the whole section is essentially semiarid in character, with an average annual precipitation of about 14 inches, most of which occurs in the spring and early summer, and with a frost-free growing season of about 125 days. The altitude of Scottsbluff is 4,000 feet, while Belle Fourche and Huntley are both 3,000 feet above sea level.

AGRICULTURAL AND SOIL CONDITIONS OF THE REGION

The agriculture of the region is relatively new, there having been very little crop production prior to 1890, and the present era of development may be said to have begun about 1900. During the 30 years or more preceding the beginning of crop production, the region was utilized chiefly as range land for cattle and horses. In recent years, despite the extension of dry-farming and irrigation, the use of the range lands for live-stock production has continued, and this industry remains an important one throughout the region.

[1] The work of this field station is conducted and supported cooperatively by the United States Department of Agriculture and the Nebraska State Experiment Station.

[2] The work at this field station is conducted and supported cooperatively by the United States Department of Agriculture and the Montana State Experiment Station.

Journal of Agricultural Research, Washington, D. C.
gl

Vol. XV, No. 9
Dec. 2, 1918
Key No. G-164

The more important crops of irrigated lands of the region are alfalfa (*Medicago sativa*), cereals, including corn (*Zea mays*), oats (*Avena sativa*), wheat (*Triticum aestivum*), and barley (*Hordeum* spp.), sugar beets (*Beta vulgaris*), and Irish potatoes (*Solanum tuberosum*). On the three reclamation projects referred to above, comprising 150,000 acres, these crops occupy nearly 90 per cent of the land, in the following proportions: Alfalfa, 43 per cent; cereals, 31 per cent; sugar beets, 10 per cent, and potatoes, 3 per cent.

The soils are generally very productive, and, notwithstanding the hazards of occasional hail storms and of the occurrence of insect pests and plant diseases, abundant crops are produced. The North Platte Project, which includes the Scottsbluff Station, has a light sandy soil which takes water readily and is subject to wind erosion when left exposed without a plant cover. The Belle Fourche soil is a heavy black clay, very plastic when wet, becoming friable on drying, when large shrinkage cracks are formed through which water penetrates the dry soil rapidly. The soil at Huntley is not quite so heavy as that at Belle Fourche, though it would be classed as a clay loam. It is very productive, except where the salt content is too high.

DESCRIPTION OF THE EXPERIMENTS

The experiments here discussed are a part of a large series of rotation experiments conducted under irrigation at each of the three stations. These rotation experiments were started with the crop season of 1912 and have been continued without modification. The field plots include ¼ acre each. These are laid out in series which are separated by 40-foot roads, and the plots in the series are separated by 5-foot alleys. The plots at Scottsbluff are 132 feet long by 82.5 feet wide. Those at Belle Fourche are 264 feet long by 41.25 feet wide, and those at Huntley are 227 feet long by 48 feet wide.

The present paper deals only with the effect of manure on the yields and qualities of two crops, sugar beets and potatoes, at the three stations for the 6-year period 1912 to 1917. The results are based on five pairs of rotations, the two members of each pair differing from each other only in that farm manure is applied annually, at the rate of 12 tons per acre, to one crop in one rotation, and no manure is applied to the other rotation. Each rotation occupies as many plots as there are years in the cycle, so that each crop is represented each year. The crops and sequences involved in the 10 rotations are as follows:

Rotation 20: Potatoes; sugar beets.
Rotation 21: Potatoes (manured); sugar beets.
Rotation 22: Oats; sugar beets.
Rotation 23: Oats; sugar beets (manured).
Rotation 24: Oats; potatoes.
Rotation 25: Oats; potatoes (manured).
Rotation 30: Potatoes; oats; sugar beets.
Rotation 31: Potatoes; oats; sugar beets (manured).
Rotation 60: Potatoes; oats; sugar beets; alfalfa, first year; alfalfa, second year; alfalfa, third year.
Rotation 61: Potatoes; oats; sugar beets (manured); alfalfa, first year; alfalfa, second year; alfalfa, third year.

With respect to any given plot the same crop recurs with each cycle of the rotation. Thus in the six years since 1912 the crops in the 2-year rotations have been on the same plot three times, those in the 3-year rotations have been on the same plot twice, while in the 6-year rotations only one cycle has been completed. In the case of the 2-year and 3-year rotations, in which manure is applied to one of the crops, this manured crop has received each year the immediate benefit of the manure and in addition the benefit of any residual effect that may have remained from the earlier applications. This becomes true also in the 6-year rotations after the completion of the first cycle.

One pair of the 2-year rotations and the pair of 3-year rotations include both sugar beets and potatoes. In the 2-year rotation, No. 21, the manure is applied preceding the potatoes and the beet crop that follows gets only the second-year residual effect of the manure. In the 3-year rotation, the manure is applied preceding the sugar beets and the potatoes receive the second-year residual effect. In the other rotations the effect of the manure is noted only in respect to the crop which immediately follows its application.

The cultural operations used with these rotations are only such as ordinary good farming demands. So far as the rotation pairs are concerned, all cultural operations are the same for both members of the pair. The same varieties of the two crops are used in all rotations at each station each year. The same varieties are not used at the different stations; nor has the same variety been used for all years at each station. For the sugar beets the seed has usually been obtained from the local sugar factory, and for the potatoes some good locally adapted variety has been used.

The field work of these rotation experiments has been under the direction of the farm superintendent of each station, and under the immediate supervision of a scientific assistant, who is charged with performing or directing the cultural operations, the irrigation, the harvesting, and taking the field notes and reporting the results each year.[1]

RESULTS OF THE EXPERIMENTS

IRISH POTATOES

The effect of the manure on the yield of potatoes is shown in Table I, which gives the yields in bushels per acre for the manured plots and the yields from plots that have had similar treatment, except for the manuring.

[1] The following is the personnel concerned with the field work of these rotation experiments: At Scottsbluff Mr. Fritz Knorr was superintendent of the field station from 1910 to the end of 1916. Mr. James A. Holden was in charge of the irrigated rotations at this station from 1912 to the end of 1916, when he succeeded Mr. Knorr as station superintendent. Mr. David W. Jones supervised the irrigated rotations during 1917.

At Bellefourche Mr. Beyer Aune has been superintendent of the field station since 1909. He has been closely in touch with the irrigated rotation work, being assisted in it at different times by Mr. John B. Wentz, Mr. N. L. Mattice, and Mr. George T. Ratliffe.

At Huntley Mr. Dan Hansen has been superintendent of the field station since 1910. The irrigated rotations were under the supervision of Mr. John M. Spain during 1912, Mr. John W. Knorr during 1914 and Mr. Edward G. Noble since 1915.

In rotations 21 and 25 manure was applied each year preceding the potato crop, while in rotation 31 the manure was applied for the sugar-beet crop which preceded the potatoes. The annual differences in yield between the manured and unmanured plots are also shown in the tables, together with the mean annual yield of the crop in each rotation and the mean of the annual differences in yield. With each of the means the probable error is given.[1]

TABLE I.—*Effect of manure on the yields of Irish potatoes at the Scottsbluff, Nebr., Belle Fourche, S. Dak., and Huntley, Mont., field stations, 1912 to 1917*

[The yields, differences, and means are expressed in bushels per acre]

SCOTTSBLUFF

Rotation No.	1912	1913	1914	1915	1916	1917	Mean.
20 (no manure)	194	398	146	88	142	131	183±28.4
21 (manure)	230	316	237	147	155	187	212±18.5
Difference	+36	−82	+91	+59	+13	+56	+29±16.0
24 (no manure)	252	235	146	109	217	134	182±19.9
25 (manure)	230	348	253	148	216	182	229±18.0
Difference	−22	+113	+107	+39	−1	+48	+47±15.9
30 (no manure)	268	329	216	146	226	167	225±18.5
31 (manure)	[a] 250	353	243	175	244	211	246±13.9
Difference	−18	+24	+27	+29	+18	+44	+21± 5.6

BELLE FOURCHE

Rotation No.	1912	1913	1914	1915	1916	1917	Mean.
20 (no manure)	71	128	86	102	157	133	113±10.0
21 (manure)	59	133	117	192	170	190	144±15.3
Difference	−12	+5	+31	+90	+13	+57	+31±10.8
24 (no manure)	13	109	112	111	151	120	103±11.0
25 (manure)	41	95	101	168	162	135	117±14.1
Difference	+28	−14	−11	+57	+11	+15	+14± 7.2
30 (no manure)	50	74	68	59	166	139	93±15.1
31 (manure)	[a] 54	90	140	137	188	205	136±16.0
Difference	+4	+16	+72	+78	+22	+66	+43±11.0

[a] No manurial effect on this crop.

[1] The probable error of the mean as used in these tables is obtained by Merriman's formula 36, which is stated as follows: $r_0 p = \frac{0.8453 \Sigma v}{n\sqrt{n-1}}$. In other words, the probable error is obtained by multiplying the sum of the departures from the mean by the quotient of $n\sqrt{n-1}$ into 0.8453, where n equals the number of yields involved (MERRIMAN, Mansfield. METHOD OF LEAST SQUARES. ed. 8. 1913).

TABLE I.—*Effect of manure on the yields of Irish potatoes at the Scottsbluff, Nebr., Belle Fourche, S. Dak., and Huntley, Mont., field stations, 1912 to 1917*—Continued

HUNTLEY

Rotation No.	1912	1913	1914	1915	1916	1917	Mean.
20 (no manure)	274	200	179	350	228	241	245±16.8
21 (manure)	270	226	176	386	294	277	271±18.0
Difference	−4	+26	−3	+36	+66	+36	+26± 7.5
24 (no manure)	263	316	171	273	236	229	248±13.6
25 (manure)	413	362	201	374	324	292	328±21.0
Difference	+150	+46	+30	+101	+88	+63	+80±12.6
30 (no manure)	208	188	156	228	224	175	196± 8.9
31 (manure)	[a] 199	160	140	273	212	91	179±18.5
Difference	−9	−28	−16	+45	−12	−84	−17± 9.7

[a] No manurial effect on this crop.

The results given in Table I, which refer to the total yield of potatoes, show that in 8 of the 9 cases the application of manure was followed by increased yields, and it should be remembered that these crops were produced on new land, where good yields are obtained even without manuring.

Each year since 1913 it has been the practice in connection with these experiments to sort the potatoes in the field at the time of digging. This sorting has been done by means of a wire screen with 2-inch meshes. The smaller potatoes that pass through this screen are classed as unmarketable, while those passing over the screen are classed as marketable. It has been observed at Scottsbluff and at Belle Fourche not only that the manured crops have been larger than those not manured, but also that the proportion of marketable potatoes has been larger on the manured land. This has not so far proved to be the case at Huntley. The yields of marketable potatoes at the three stations for the three pairs of rotations for five years are given in Table II, together with the annual differences and the mean yields and the mean of the annual differences.

TABLE II.—*Effect of manure on the yields of marketable Irish potatoes at the Scottsbluff, Nebr., Belle Fourche, S. Dak., and Huntley, Mont., field stations, 1913 to 1917, inclusive*

[The yields, differences, and means are expressed in bushels per acre]

SCOTTSBLUFF

Rotation No.	1913	1914	1915	1916	1917	Mean.
20 (no manure)	243	74	47	119	98	116±21.9
21 (manure)	208	156	101	129	153	149±11.7
Difference	−35	+82	+54	+ 10	+55	+33±15.5
24 (no manure)	101	75	68	185	110	108±13.4
25 (manure)	251	190	102	192	164	180±15.8
Difference	+150	+115	+34	+ 7	+54	+72±20.5
30 (no manure)	194	143	101	197	147	156±13.2
31 (manure)	237	168	135	217	184	188±13.1
Difference	+43	+25	+34	+20	+37	+32± 3.1

BELLE FOURCHE

Rotation No.	1913	1914	1915	1916	1917	Mean.
20 (no manure)	87	66	93	86	97	86± 3.3
21 (manure)	104	109	175	117	163	134±12.0
Difference	+17	+43	+82	+31	+66	+48± 8.9
24 (no manure)	89	106	102	112	96	101± 2.9
25 (manure)	75	89	155	96	117	106±10.0
Difference	−14	−17	+53	−16	+21	+5±10.7
30 (no manure)	37	54	48	120	107	73±14.5
31 (manure)	76	120	127	143	182	129±11.2
Difference	+39	+66	+79	+23	+75	+56± 8.6

HUNTLEY

Rotation No.	1913	1914	1915	1916	1917	Mean.
20 (no manure)	192	152	336	201	226	221±19.2
21 (manure)	212	139	359	262	260	246±24.0
Difference	+20	−13	+23	+61	+34	+25±7.6
24 (no manure)	307	149	259	212	213	228±18.8
25 (manure)	347	181	363	298	278	293±21.6
Difference	+40	+32	+104	+86	+65	+65±10.0
30 (no manure)	179	131	212	206	159	177±11.0
31 (manure)	150	115	259	182	83	158±21.2
Difference	−29	−16	+47	−24	−76	−19±11.9

The facts set forth in Tables I and II may be summarized separately for each of the three stations for the five years 1913 to 1917, as follows:

At Scottsbluff the yield of potatoes, large and small, for the 30 plot-years, has averaged 208 bushels per acre, with a mean annual difference in favor of the manuring of 40±7. The yield of marketable potatoes from the same plots has averaged 150 bushels per acre, with a mean annual difference in favor of the manuring of 46±7. The percentage of the total yield classed as marketable for the 30 plots is 72, while the mean annual difference in percentage marketable in favor of the manuring is 8±1.5.

At Belle Fourche the total yield of potatoes for the 30 plot-years has averaged 131 bushels per acre, while the mean annual difference in favor of manuring is 34±6.4. The yield of marketable potatoes from the same plots has averaged 105 bushels per acre, while the mean annual difference in favor of the manuring is 36±6.3. The percentage of the total yield classed as marketable for the 30 plots is 80, while the mean annual difference in percentage marketable in favor of the manuring is 7±1.9.

At Huntley the total yield of potatoes for the 30 plot-years has averaged 239 bushels per acre, while the mean annual difference in favor of manuring is 26±8.3. The yield of marketable potatoes from the same plots has averaged 221 bushels per acre, while the mean annual difference in favor of the manuring is 24±8.5. The percentage of the total yield classed as marketable for the 30 plots is 92, while the mean annual difference has been negligible, being in favor of the manured plots by less than 1 per cent.

SUGAR BEETS

The effect of manure on the yields of sugar beets is shown in Table III, which gives the annual yields in tons per acre for the manured and unmanured plots and the annual differences in yield between the pair of plots that have had similar treatment except for the manuring. The table also shows the mean annual yield of the crop for each rotation for six years and the mean of the annual differences with the probable errors of these means obtained as indicated above in the discussion of Table I.

In the 12 comparisons shown in Table III the mean yields for the 6-year period all show increases as a result of manuring. Some of these increases are too small to be considered significant, but in 9 cases of the 12 the mean of the annual differences exceeds its probable error sufficiently to be regarded as significant. Eliminating the 3 cases of rotation 21 in 1912, in which the manure had not been applied, there remain 69 annual comparisons. Of these annual comparisons 62 show increased yields following the application of manure and only 7 show decreased yields.

In rotation 21 the manure is applied for the potato crop, which precedes the sugar beets, so that the later crop receives only the second-year effect of the manure. In rotations 21 and 23 manure has been applied to the same plot three times during the 6-year period covered by the table.

In rotation 31 manure has been applied to the same plot twice during the period, while in rotation 61 only one cycle has been completed, and no residual effect of previous applications of manure is to be observed.

TABLE III.—*Effect of manure on the yield of sugar beets at the Scottsbluff, Nebr., Belle Fourche, S. Dak., and Huntley, Mont., field stations, 1912 to 1917, inclusive*

[The yields, differences, and means are expressed in tons per acre]

SCOTTSBLUFF

Rotation No.	1912	1913	1914	1915	1916	1917	Mean.
20 (not manured)	15.3	19.6	14.5	10.6	5.8	13.0	13.0±1.3
21 (manured)	[a]13.5	20.8	17.2	13.1	6.4	17.0	14.6±1.4
Difference	−1.8	+1.2	+2.7	+2.5	+ .6	+4.0	+1.6± .58
22 (Not manured)	13.9	18.3	14.2	12.0	7.3	11.1	12.8±1.0
23 (manured)	19.4	21.4	19.9	15.9	9.4	18.6	17.4±1.2
Difference	+5.5	+3.1	+5.7	+3.9	+2.1	+7.5	+4.6± .6
30 (not manured)	17.6	17.0	13.9	10.2	9.8	9.1	12.9±1.2
31 (manured)	21.4	23.8	17.4	15.6	17.1	16.0	18.5±1.0
Difference	+3.8	+6.8	+3.5	+5.4	+7.3	+6.9	+5.6± .52
60 (not manured)	17.3	17.2	14.8	12.5	7.3	15.3	14.1±1.0
61 (manured)	22.4	23.4	18.5	15.3	11.9	19.5	18.5±1.2
Difference	+5.1	+6.2	+3.7	+2.8	+4.6	+4.2	4.4± .33

BELLE FOURCHE

Rotation No.	1912	1913	1914	1915	1916	1917	Mean.
20 (not manured)	7.0	10.7	11.3	12.2	9.7	15.3	11.0±0.7
21 (manured)	[a]7.0	8.8	14.6	16.0	12.1	18.6	12.8±1.3
Difference	.0	−1.9	+3.3	+3.8	+2.4	+3.3	+1.8± .7
22 (not manured)	7.6	7.6	12.3	9.1	8.1	17.7	10.4±1.1
23 (manured)	5.7	8.3	10.6	11.8	9.6	20.9	11.1±1.3
Difference	−1.9	+ .7	−1.7	+2.7	+1.5	+3.2	+ .7± .65
30 (not manured)	7.4	9.1	10.7	7.3	4.6	7.4	7.7±0.6
31 (manured)	8.5	9.3	14.2	13.2	8.2	15.3	11.4±1.1
Difference	+1.1	+ .2	+3.5	+5.9	+3.6	+7.9	+3.7± .8
60 (not manured)	8.5	8.0	11.2	9.4	7.2	12.7	9.5± .6
61 (manured)	7.1	6.1	12.7	10.9	10.4	15.7	10.5±1.0
Difference	−1.4	−1.9	+1.5	+1.5	+3.2	+3.0	+1.0± .56

[a] No manurial effect on this crop.

TABLE III.—*Effect of manure on the yield of sugar beets at the Scottsbluff, Nebr., Belle Fourche, S. Dak., and Huntley, Mont., field stations, 1912 to 1917, inclusive*—Con.

HUNTLEY

Rotation No.	1912	1913	1914	1915	1916	1917	Mean.
20 (not manured)	12.3	12.6	15.1	8.3	15.3	9.6	12.2±0.8
21 (manured)	[a]12.6	13.3	14.4	12.8	17.9	12.1	13.8± .6
Difference	+ .3	+ .7	− .7	+4.5	+2.6	+2.5	+1.6± .59
22 (not manured)	11.7	15.2	10.4	6.8	11.1	11.3	11.1± .6
23 (manured)	14.4	13.4	12.6	10.7	12.0	12.5	12.6± .3
Difference	+2.7	−1.8	+2.2	+3.9	+.9	+1.2	+1.5± .54
30 (not manured)	7.3	11.4	6.6	4.8	6.7	6.7	7.2± .5
31 (manured)	8.3	15.3	12.8	9.1	10.0	9.6	10.8± .8
Difference	+1.0	+3.9	+6.2	+4.3	+3.3	+2.9	+3.6± .45
60 (not manured)	9.7	11.6	9.3	12.9	7.4	8.3	9.9± .6
61 (manured)	12.2	15.8	13.6	8.7	15.6	13.0	13.2± .7
Difference	+2.5	+4.2	+4.3	−4.2	+8.2	+4.7	+3.3±1.03

[a] No manurial effect on this crop.

In addition to recording the yield of beets from the rotation plots as shown in Table III, it has been customary also to determine the average size of the beets on each plot by counting and weighing the product of several representative rows, to record the percentage of sugar in the beets as reported by the local sugar factory upon samples from each plot, and to determine the proportion of the weight of the tops to the combined weight of beets and tops. This last determination has a bearing not only as showing the vigor of growth of the sugar beets, but also as indicating the quantity of feed left as a by-product of the beet crop.

The facts regarding the effect of manure on increasing the yield of beets as shown in Table III, and also as to the effect on size of beets, percentage of sugar in the beets, and percentage of tops, are summarized for each of the three stations as follows:

At Scottsbluff the yield of beets from the 46 plot-years, omitting rotations 20 and 21 in 1912, averaged 15.3 tons per acre, while the mean annual difference in favor of the manuring is 4.3±0.28. The size of beets from the same plots averaged 1.55 pounds, with a mean annual difference in favor of the manuring of 0.32±0.044. The percentage of sugar in the beets was not determined in 1912, so that the results of only 40 plot-years are available. This averaged 16.5 per cent, with a mean annual difference in favor of the unmanured plots of 0.12±0.20, which is not significant. The percentage of the weight of top to the

combined weight of beets and tops for 46 plot-years is 26 per cent, with a mean annual difference in favor of the manuring of 2.7 ± 0.6.

At Belle Fourche the yield of beets for 46 plot-years averaged 10.7 tons per acre, with a mean annual difference in favor of the manuring of 1.9 ± 0.36. The size of beets from the same plots averaged 0.84 pound, with a mean annual difference in favor of the manuring of 0.08 ± 0.035. The percentage of sugar in the beets, omitting 1912, averaged for 40 plot-years 19.6 per cent, with the mean annual difference in favor of the manured plots of 0.3 ± 0.22. The record of the percentage of tops is incomplete.

At Huntley the yield of beets for 46 plot-years averaged 11.3 tons per acre, with the mean annual difference in favor of the manuring of 2.6 ± 0.33. The notes as to size of beets, percentage of sugar, and percentage of tops were not taken for 1912. The size of beets for 40 plot-years averaged 0.92 pound, with the mean annual difference in favor of manuring of 0.21 ± 0.034. The percentage of sugar in the beets averaged 16.8 per cent, with a mean annual difference in favor of the manuring of 0.16 ± 0.17, which is negligible.

The proportion of the weight of tops to the combined weight of beets and tops averaged 32 per cent, with a mean annual difference in favor of the manuring of 3.2 ± 1.12.

SUMMARY

The effect of manure on the yields of Irish potatoes and sugar beets under irrigation has been tested for six years in seven rotations at each of three different stations in the northern Great Plains. Comparison is made between the yields of these crops when grown in rotations without manure and when grown in the same sequence in other rotations in which manure is applied at the rate of 12 tons per acre once during the cycle of the rotation.

At Scottsbluff, Nebr., the effect of the manure has been to increase the yield of potatoes about 40 bushels per acre, to increase the proportion of marketable potatoes about 8 per cent, and to increase the yield of sugar beets 4.3 tons per acre without materially affecting the sugar content of the beets.

At Belle Fourche, S. Dak., the effect of the manure has been to increase the yield of potatoes about 34 bushels per acre, to increase the proportion of marketable potatoes about 7 per cent, and to increase the yield of sugar beets 1.9 tons per acre without materially affecting the sugar content of the beets.

At Huntley, Mont., the effect of the manure has been to increase the yield of potatoes about 26 bushels per acre without influencing materially the proportion of marketable potatoes, and to increase the yield

of sugar beets 2.6 tons per acre without materially affecting the sugar content of the beets.

In five of the seven rotations considered the increased yields were from the crop immediately following the application of the manure. In the other two rotations the yields were from crops produced the second season after the manure was applied. The increases in yield shown in these two cases, as well as the effects observed with other crops grown in these rotations, show that the benefit of the manure is appreciable for two years or more after it was applied.

RELATION OF INORGANIC SOIL COLLOIDS TO PLOWSOLE IN CITRUS GROVES IN SOUTHERN CALIFORNIA

By Charles A Jensen

Assistant in Plant Malnutrition, Biophysical Investigations, Bureau of Plant Industry, United States Department of Agriculture

The term "plowsole" as here used refers to the hard layer of soil artificially formed in Citrus groves in southern California when the soil is intensively cultivated during the irrigation season. Its upper limit is the lower limit of the soil mulch established by cultivation, and it has been found to vary in thickness from a few inches to 2 feet, though usually it does not extend below the first 18 inches of the soil. The hardness of the plowsole varies from a perceptible crust to a layer difficult to penetrate with a shovel. Immediately after irrigation it is usually soft, and is then easily broken; as the soil dries, the plowsole layer hardens again.

If soil from groves, or from the surrounding native desert areas, is put into pots in the laboratory, irrigated, and the surface layer stirred to form a soil mulch, a hard crust will be formed under the mulch by the time all the soil is dry. The soil just below the crust usually retains a crumbly structure, and does not harden. This plowsole occurs as the result of a single irrigation followed by a few surface cultivations. It thus appears that the packing caused by teams and implements is not necessary for its formation.

Plowsole has been found to occur in all soil types investigated in the Riverside, Redlands, and Corona areas. Coarse granitic soils, as well as the heavier clay loam soils, are subject to plowsole formation. It has not, however, been observed to form under the trees where the soil has not been cultivated, especially when an organic mulch has been maintained; nor has it been found in basins mulched with organic matter. When the organic mulch is not maintained, the immediate surface soil crusts; but the crust is formed simply by the drying out of the surface soil.

In many groves the fibrous Citrus roots do not readily penetrate the plowsole, though roots are often found in the hard layer. It appears that in such cases of penetration the roots are formed during the rainy season when the plowsole is soft and maintained in a moist condition. Between irrigations in the summer time the upper part of the plowsole itself dries out below the moisture content necessary to maintain root growth.

Journal of Agricultural Research, Washington, D. C.
qm

Vol. XV, No. 9
Dec. 2, 1918
Key No. G-165

In other groves it was found that the fibrous roots grew freely into the uncultivated surface soil under the trees, but not at all into the plowsole layer formed in the area frequently cultivated.

In addition to checking the root growth and limiting the soil layer available for the root development of the shallow-rooted Citrus trees, the plowsole seriously checks the penetration of the irrigation water.

The condition may be temporarily relieved by breaking up the plowsole layer with a subsoiler, but the plowsole forms again when cultivation is resumed. The best remedy against the formation of plowsole seems to be a surface organic mulch, with no cultivation during the irrigation season beyond that necessary to keep weeds under control.

The present report deals with some of the properties of plowsole as found in citrus groves or formed artificially in the laboratory. The work was done in Riverside, Cal., on soil samples from that area.

COMPOSITION OF WATER EXTRACT OF PLOWSOLE

Soil samples were collected from eight orange groves in which plowsole occurred. Samples at three different depths were collected, including (1) the soil mulch, usually 3 to 5 inches deep; (2) the plowsole crust; (3) the subsoil under the plowsole.

Each sample was rolled, passed throgh a 2-mm. sieve, extracted with distilled water in the ratio of 1 part of soil to 2 parts of water, and the extract analyzed. The water extracts of the soil samples from four of the groves were filtered through Chamberland porous filter tubes, and the water extracts of the samples from the other four groves were filtered through filter paper.

Table I shows the average amounts, in parts per million on the basis of dry soil, of iron, calcium, magnesium, and silica found in the respective soil layers. Each figure is the average in samples from four groves.

The elements determined are those usually considered to have a cementing action in soil, and with one exception there was evidently no accumulation of these in the plowsole. Mineral carbonates were present in the soils included in these analyses only in traces or very small amounts.

The comparatively large amount of iron in the water extracts of the plowsole filtered through filter paper is due to one exceptionally high determination—viz, 9 p. p. m. The average amount of iron in this layer in the three other groves was 1.07 p. p. m., and this amount evidently more nearly represents the true condition in respect to iron. In the large number of iron determinations made in water extracts of soils in the area considered, the highest amount found was 2.7 p. p. m., excepting the one mentioned above. The average amounts of iron in eight other water extracts of soil mulch, plowsole, and subsoil were, respectively, 0.88, 0.58, 0.87 p. p. m. on the dry soil. It would therefore seem that 1.07 p. p. m. of iron in the plowsole is a more reliable figure than 3.05 parts, as shown in Table I, when the water extracts were filtered

through filter paper. Unfortunately these soil samples were discarded before this apparent error was detected, the analytical work having been done in May, 1916, and the results not having been carefully tabulated and compared until April, 1917, owing to other work.

TABLE I.—*Analysis of water extracts of soil mulch, plowsole, and subsoil from orange groves. Average of four groves*

[Results reduced to basis of dry soil and expressed as p. p. m.]

Soil layer.	Through Chamberland filters.				Through filter paper.			
	Iron.	Calcium.	Magnesium.	Silica.	Iron.	Calcium.	Magnesium.	Silica.
Mulch	0.61	117	17	13	0.94	70	17	30
Plowsole	.28	23	4	9	[a] 3.05	35	7	27
Subsoil	.31	41	4	9	1.40	29	10	23

[a] Leaving out one exceptionally high determination, the average of the other three groves is 1.07 p. p. m. of iron (see text).

Flowerpots were filled with soil from some of these groves, placed in the laboratory, irrigated several times, and kept mulched. A number of inorganic salts, carbonates, chlorids, nitrates, and phosphates, were mixed with some of the soils. Plowsole layers formed readily under the soil mulch.

After about one month the soil mulch, plowsole, and subsoil were separately extracted with distilled water and analyzed. There was no accumulation of the water-soluble cementing elements in the plowsole layers in either the treated or untreated soils.

The plowsole layers in the differently treated soils varied greatly in hardness. The hardest layers occurred in the soils treated with sodium chlorid, sodium nitrate, sodium phosphate, magnesium sulphate, and sodium carbonate. The softest layers were formed in the soils mixed with calcium carbonate, calcium sulphate, and alfalfa.

Soils from the four orange groves, the soil analysis of which were presented in Table I, were extracted with 1 per cent hydrochloric acid until calcium was absent, washed with distilled water, and then extracted with 4 per cent ammonium hydrate. The ratio of soil to ammonium hydrate was 100 gm. to 500 cc. The "humus" extracts were evaporated to dryness and ignited just enough to drive off the organic matter. There were no facilities on hand at the time for fusion, so the residues were digested with nitrohydrochloric acid on the water bath until no perceptible residue remained.

Partial analyses of these dissolved residues are given in Table II. Each figure represents the average percentage obtained on the analysis of extracts of soils from eight groves.

TABLE II.—*Analysis of humus extracts of soil mulch, plowsole, and subsoil from orange groves. Average percentage of eight groves*

Soil layer.	Percentage, on basis of dry soil, in ammonia extract.			
	Silicon dioxid.	Ferric oxid.	Aluminium oxid.	Phosphorus pentoxid.
Mulch	0.032	0.006	0.015	0.013
Plowsole	.027	.008	.011	.012
Subsoil	.024	.007	.011	.011

There is no evident accumulation of these elements in the plowsole that would account for its formation.

Another set of ammonium extracts was made from samples of the same soils. The colloidal material was precipitated with a little nitric acid, and filtered out. The filtrate was next treated with a little ammonium carbonate, and again filtered. The two precipitates were taken up with a little ammonium hydrate, evaporated to dryness, and ignited just enough to burn off the organic matter. The ignited material was digested as before with nitrohydrochloric acid on the water bath until no perceptible residue remained, and the solution was analyzed. Table III gives the results of the partial analyses made, each figure being the average percentage found in soils from eight different groves.

TABLE III.—*Analysis of inorganic colloids in humus extracts of soil mulch, plowsole, and subsoil from orange groves. Average percentage in soils from eight groves*

Soil layer.	Percentage on basis of dry soil.				
	Silicon dioxid.	Ferric oxid.	Aluminium oxid.	Phosphorus pentoxid.	Silica, iron, and aluminium.
Mulch	0.016	0.005	0.016	0.004	0.037
Plowsole	.030	.008	.025	.004	.063
Subsoil	.015	.006	.018	.003	.039

There is thus an accumulation of colloidal iron, aluminium, and silica in the plowsole layer. The detailed analyses showed this to be consistently the case for each grove.

The analyses given in Tables II and III were made on ammonia extracts of the same composite samples, but each table represents a separate extraction on fresh samples. Hence, the ratio of the colloidal elements to the total amounts of these same elements determined in the ammonia extracts can not be definitely stated from the data obtained. A comparison of Tables II and III, however, would indicate that only about one-third of phosphoric acid was present in the colloidal form in the

ammonia extract, and that practically all the iron was present in that form. It would also appear that practically all the silica and aluminium in the plowsole layer were colloidal.

Fraps (*4*)[1] used ammonium carbonate to precipitate the inorganic soil colloids from ammoniacal solutions. It was found in this work that a little more inorganic material was obtained by precipitating the extract successively with nitric acid and ammonium carbonate. The acid carried down practically all the organic matter as well, as judged by color.

The following experiment shows the results obtained by precipitating the colloids from ammonia extracts of a soil, with nitric acid and ammonium carbonate as precipitants. Two 150-cc. portions of a composite ammonia humus solution were treated separately with nitric acid and ammonium carbonate. The filtrate from the acid-treated extract was then treated with ammonium carbonate, and the filtrate from the carbonate-treated extract was treated with nitric acid. Each separate precipitate was ignited and weighed. The results obtained are given in Table IV.

TABLE IV.—*Comparison of efficiency of nitric acid and ammonium carbonate in precipitating inorganic colloids from ammonia extracts of soil*

First precipitant.	Weight of ignited precipitate.	Second precipitant.	Weight of ignited precipitate.
	Gm.		*Gm.*
Ammonium carbonate	0.0200	Nitric acid	0.0020
Nitric acid	.0202	Ammonium carbonate	.0049

It appears that these two precipitants were about equally effective in precipitating the inorganic colloids from humus solutions. When the two were used successively, an appreciable increase in inorganic material was obtained. The results of the first precipitations would indicate that the flocculated organic matter caused by addition of nitric acid did not carry down or occlude noncolloidal mineral substances.

Samples of soil mulch, plowsole, and subsoil from four other orange groves not included in the discussion so far, were extracted with hydrochloric acid till calcium was absent, washed, and extracted with ammonium hydrate. The inorganic colloids were precipitated as just described, ignited, and weighed. The average percentage of total inorganic soil colloids in the humus extracts of the separate soil tamples from the four groves was as follows: Soil mulch, 0.0642; plowsole, 0.0912; subsoil, 0.073.

These results agree with those given in Table III, in showing that an accumulation of ammonia-soluble inorganic soil colloids occurs in the plowsole layers.

[1] Reference is made by number (italic) to "Literature cited," p. 518–519.

The organic and inorganic colloidal material in these humus extracts evidently moves with the electric current, as the following experiment shows:

Two tubes were connected together with rubber tubing into the form of a U-tube, and filled with humus extract. Electrodes from a battery of six new dry cells connected in series were inserted into the tops of the U-tube touching the extract, and left undisturbed for seven days. The liquid in the two tubes was then separated by closing the rubber-tube connection. A colorimetric humus reading was made of the liquid in each tube. The inorganic colloids were precipitated with nitric acid and ammonium carbonate, ignited and weighed. Table V gives the results obtained.

TABLE V.—*Inorganic colloids and humus in humus extracts of soil in positive and negative sides of the U-tube*

Electric charge in U-tube.	Percentage of inorganic colloids in solution.	Percentage of humus in solution.
Positive	0.0380	0.0625
Negative	.0230	.0500

In the preceding discussion it has been shown that there is evidently no accumulation of water-soluble iron, calcium, magnesium, or silica in the plowsole layers that could account for its formation; that the total ammonia-soluble silica, iron, aluminium, or phosphoric acid could not account for the formation of the plowsole; and that there was accumulation of ammonia-soluble colloidal silica, iron, and aluminium, in the plowsole, but not of colloidal phosphoric acid.

The last-mentioned fact indicated the desirability of making a direct study of the inorganic colloidal material in the soil.[1]

The term "colloid suspension" will be used frequently in what follows, and for the purpose of clearness it will be used to mean simply the inorganic material of a soil remaining in suspension at the end of 24 hours after the soil has been treated in a certain manner.

The following conventional method was adopted for determining the percentage of colloid suspension in the soils. Five gms. of soil were placed in a 250-cc. Erlenmeyer flask, 50 cc. of distilled water was added, the flask covered with a watch glass and placed on the water bath. The contents were shaken periodically, and after 1½ hours the suspended material was decanted into a test tube about 3 cm. in diameter and 25

[1] A discussion of the general properties of colloids will not be entered into here. Whether colloids are classified according to size, chemical constitution, or method of preparation will have but little bearing on the nature of the present work. Excellent discussions on colloids are given by Ostwald (OSTWALD, Wolfgang. HANDBOOK OF COLLOID-CHEMISTRY, . . . Trans. from 3d German ed. 278 p., 60 fig. Philadelphia); and by Burton (BURTON, E. F. PHYSICAL PROPERTIES OF COLLOIDAL SOLUTIONS. 200 p., 18 fig. London, New York), not to mention many other earlier workers in the field.

cm. high. Another portion of 50 cc. of distilled water was added to the soil remaining in the flask, and the former treatment repeated. The same treatment was repeated a third time, and on the third decantation all the soil was washed into the test tube. The tube finally contained about 180 cc. and was left undisturbed for 24 hours. The suspeuded material was then carefully siphoned off and precipitated with neutral ammonium sulphate. The precipitation was hastened hy warming. The precipitate was filtered, ignited, and weighed as the percentage of "colloid suspension."

Duplicate determinations were made, and the departure varied from nothing to a maximum of about 5.5 per cent. When the departure did not exceed 3.5 per cent the results were used. When the error was greater, duplicate determinations were again made.

It was found to be more difficult to obtain two uniform duplicate 5-gm. soil samples than to make good duplicate determinations on a very uniform sample of soil "colloid" used for experimental purposes. To insure better duplicate sampling for colloid determinations, the soil as taken from the groves was rolled and sifted through a 2-mm. sieve.

It is realized that this method of measuring the colloidal content of soils does not show the absolute amount of colloid in a soil. The colloidal content by this method is necessarily affected by tle amount and character of the electrolytes going into solution. The purpose of the measurements was not to get a measurement of the absolute colloidal content, but to study the relative colloidal content in the three layers of soil in plowsole groves. Ashley (*1*) measured the colloid matter in clay by the absorption of dyes in the study of the plasticity of clay. His work has a special bearing on the ceramic industries. This method does not appear applicable to the present work, since it is probable that not only the colloid matter remaining in suspension after 24 hours, hut the colloidal matter not remaining in suspension as well would absorb dyes; and so in all likelihood would the organic matter in the soil, which was found to bear no relation to the percentage of inorganic colloid suspension in the soil. The purpose of the present study was to obtain a measurement of the colloid matter that was free to move with the soil moisture, as it seemed to do.

That the method of determining the colloid suspension as above described is entirely conventional is shown by the following experiment. Five-gm. soil samples from a composite sample were put into Erlenmeyer flasks, distilled water was added, and the flasks were placed on the bath. The total amount of water used and the total time of the sample on the bath were the same for each determination. In each case, also, the suspended matter as transferred to the test tubes stood 24 hours before being siphoned off. The variable factor was the number of decantations and consequently the amount of water used for each. Table VI gives the results of the determinations and the condition of each test.

TABLE VI.—*Inorganic colloid suspension in soil as influenced by successive decantations with small amounts of distilled water and by single decantation with larger amounts of water, total time on water bath being the same in all cases*

Number of decantations.	Quantity of water with each decantation.	Time on water bath each decantation.	Percentage of colloid on soil.
	Cc.	*Hours.*	
3	60	2.5	0.476
2	85	3.75	.418
1	175	7.5	.338
1	[a] 175	7.5	.847

[a] 3 cc. of ammonium hydrate added.

Soil mulch, plowsole, and subsoil samples taken in groves having plowsole, were rolled (not crushed), sifted through a 2-mm. sieve, and subjected to colloid-suspension determinations. The average percentage of the inorganic colloid suspension in soil samples from seven different groves was as follows: Mulch, 0.879; plowsole, 1.334; subsoil, 1.215. In all groves but one the colloid content was greater in the plowsole than in either the soil mulch or subsoil. The grove which proved the exception was sampled a second time and subjected to colloid-suspension determinations, which gave results similar to the first determinations.

There is thus an accumulation of inorganic colloid matter in the plowsole layer, especially as compared with the soil-mulch layer.

From laboratory experiments it would appear that this colloid matter migrates with the soil moisture much as do soluble salts, though probably much more sluggishly. Soils from groves were put in flowerpots in the laboratory and irrigated, the soil being allowed to dry out before each irrigation and before the colloid determinations were made. In every instance after one or more irrigations the surface layer of soil was found to contain a greater percentage of inorganic colloid suspension than the subsurface soil. The increase in colloid matter in the surface layer varied from 11 to 70 per cent.

The inorganic colloid condition of the soil is largely governed by the composition of the soluble salts present. The sulphates of sodium, ammonium, and calcium tend to precipitate the colloids, while the nitrates, carbonates, and bicarbonates have the reverse effect.

It is not uncommon to find considerable accumulation of "alkali" salts on the irrigation furrow slopes in Citrus groves after irrigation. Breazeale (*2*) has analyzed some of these and found the predominant salts to be sulphates and nitrates, the latter being present in the greater quantity. McBeth (*6*) has shown that nitrates are at times present in large amounts on the slopes of the irrigation furrows. The latter's work shows also the relation of nitrate accumulation to the rainfall, which is of importance in the present discussion. Finally the irrigation

waters used in the area here under consideration carry more bicarbonates than sulphates (3).

As a whole the deflocculating salts predominate over the flocculating salts in the cases examined by the Office of Biophysical Investigations in Citrus groves in southern California. Hence, so far as the readily soluble soil salts are concerned, the tendency would be for the inorganic colloid matter to be carried down into the soil by irrigation water and rains. As a surface soil mulch is established in most cases as soon as possible, the colloid matter would naturally tend to remain below this layer.

After the winter rains it was found that the amount of electrolytes in the plowsole layer exceeded that in the soil surface by about 60 per cent, as determined by conductivity measurements. The accumulation of soluble salts in the plowsole layer would probably tend to precipitate the colloids, and the denser physical structure of this layer would act as a filter.

No relation could be established between the percentage of colloid suspension and the percentage of humus or organic carbon in the soil. The addition of organic matter to soil, however, was found to influence the inorganic colloid state in the soil. Various organic substances were added to soils from orange groves, and the treated soils put into flowerpots in the laboratory. These were irrigated intermittently for a period of over one year. The soils were then taken out, rolled, sifted through a 2-mm. sieve, and subjected to inorganic colloid-suspension determinations. Table VII gives the results obtained.

TABLE VII.—*Effect of the addition of organic matter to soils on the amount of inorganic colloid suspension. Organic matter in contact with the soils for more than a year*

Organic treatment.	Percentage of inorganic colloid suspension.				
	Sandy loam.		Clay loam.		
	Manure (soil C).	Alfalfa (soil A).	Manure (soil D).	Alfalfa (soil F).	Barley (soil H).
Untreated	0.422	0.511	0.764	0.778	0.852
1 per cent of organic matter	.314	....	.855	.965	.707
3 per cent of organic matter	.229	.372	.755	.787	.675

In most cases the addition of 3 per cent of organic matter decreased the amount of inorganic colloid matter, while 1 per cent had less effect. Apparently the state of the colloid matter was more influenced by organic treatment in the sandy-loam soil than in the clay-loam soil.

It is possible that the effect of the organic matter on the amount of colloid suspension in the above experiment is due in part to the indirect effect of the change in content of soluble salts. It has been found that the addition of organic matter to soils very appreciably affects the solu-

bility of the soil minerals (5). The nature of the compounds thus produced has not been investigated, nor has the effect of the by-products of the decomposition on the inorganic colloid matter of the soil.

The addition of 1 per cent of organic matter represents approximately 10 tons dry matter per acre 6 inches. This is probably more than is usually applied per acre, at any one time in commercial citriculture in southern California. The improvement in the physical condition of the soil by the addition of organic matter in the customary amounts would thus hardly seem to be due to any marked changes in the state of the inorganic colloid matter of the soil but rather to the mechanical separation of the soil aggregates.

Soil from the same groves represented in Table VII was treated with certain organic and inorganic substances, put into pots in the laboratory The soils were irrigated intermittently for over a year. The soils were then rolled, passed through a 2-mm. sieve, and subjected to inorganic colloid determinations. Table VIII gives the results obtained.

TABLE VIII.—*Effect of the addition of certain organic and inorganic substances to soils on the amount of inorganic colloid suspension. Substances in contact with the soils for more than a year*

Inorganic treatment.	Percentage of inorganic colloid suspension.								
	Clay loam.							Sandy loam, organic treatment (soil C).	
	No organic treatment (soil B).	Organic treatment.							
		Soil D.		Soil F.		Soil H.			
		Control.	3 per cent manure.	Control.	3 per cent alfalfa.	Control.	3 per cent barley.	Control.	3 per cent manure.
Control:									
Untreated	0.931	0.764	......	0.778	......	0.852	......	0.422	......
Organic matter alone (3 per cent)	......	......	0.755	......	0.787	......	0.675	......	0.229
Lime carbonate:									
1 per cent	.540	......	.707	......	.614	......	.584	......	.214
3 per cent	.517	......	.579	......	.611	......	.497	......	.202
Sulphur:									
0.5 per cent	.234	......	......	......	.210	......	.193	......	.260
0.2 per cent	......	......	.520	......	......	......	......	......	.235
Sodium nitrate	1.206	......	.839	......	.991	......	.870	......	.208
Gypsum	.244	......	.211	......	.280	......	.330	......	

All the clay-loam soils are from the same large composite sample, but, owing to the impossibility of selecting samples entirely comparable, each soil number should be considered as a separate experiment. It would seem evident, however, that the organic matter tended to counteract the flocculating effect of the lime in the clay-loam soil. The organic

matter also counteracted the deflocculating effect of the nitrate. The barley was more effective in these respects than the other organic substances. Organic matter showed no consistent effect on the flocculating effect of sulphur and gypsum. In the sandy-loam soil it is apparent that the addition of lime to the organic matter had but little effect in decreasing the inorganic colloid matter.

The action of the sulphur in flocculating the colloid matter is probably due to the formation of sulphates, which are good colloid precipitants.

Groves that had been in cultivation many years contained a much greater percentage of colloid suspension than the corresponding native-soil type adjoining.

The composition of the colloid suspension obtained from soils differently treated was partially investigated. The colloid was obtained as previously described, precipitated, ignited, weighed, and fused with anhydrous sodium carbonate in platinum crucibles. The resulting cake was taken up with distilled water and partially analyzed.

The soils used in these determinations had been treated as shown in Table IX, put into flowerpots, and irrigated and cultivated intermittently for over a year before these determinations were made.

TABLE IX.—*Partial analysis of whole soil and of inorganic colloid suspension obtained from same soil receiving certain organic and inorganic treatments. Clay-loam soil from near Riverside, Cal., of granitic origin*

Soil treatment.	Colloid in soil.	Silicon dioxid.	Ferric oxid.	Aluminum oxid.	Calcium oxid.	Manganous oxid.	Phosphorus pentoxid.
	Percent.	*Percent.*	*Percent.*	*Percent.*	*Percent.*	*Percent.*	*Percent.*
Untreated	0.682	52.0	12.7	27.1	1.3	1.4	0.24
3 per cent of manure	.643	49.9	12.3	27.2	1.6	1.1	.31
3 per cent of manure + 3 per cent of calcium carbonate	.439	51.4	12.6	27.0	2.7	1.9	.19
3 per cent of manure + .2 per cent of sulphur	.578	50.8	13.7	25.5	2.8	1.5	.64
3 per cent of manure + .2 per cent of sodium nitrate	.737	47.0	11.8	27.8	2.9	1.3	.50
3 per cent of manure + 1.8 per cent of iron sulphate	.375	49.6	12.7	27.9	3.6	2.5	.48
3 per cent of manure + 3 per cent of calcium sulphate	.244	53.8	10.0	26.0	6.2	3.0	.62
Whole soil		61.4	4.7	17.3	3.5	0.6	.18

Table IX shows the results of the partial analysis of the whole soil and of the colloid suspensions. Two evaporations were made in the silica determinations, but the silica residue was not purified with hydrofluoric acid. In this connection it may be stated that the fused cake, when taken up with water, never contained any visible undissolved residue.

The composition of the colloid suspensions from the differently treated soils does not vary enough to indicate any fundamental differences due to the soil treatments, except when gypsum was added. All other

analyses made of colloid suspensions not here included agree in showing lower iron and higher silica, calcium, and manganese in this colloid suspension than in the other suspensions. The variation in the composition of the other colloid suspensions is probably due to analytical errors. The low silica obtained on the colloid from the nitrate-treated soil is probably an analytical error, as other determinations on colloid from similarly treated soil gave about the same percentage of silica as obtained on the other colloids.

Fraps (4) found that the ammonia-soluble inorganic soil colloids varied in composition with the percentage of colloids in the soil. The percentage of silica decreased and the percentage of aluminium increased with increasing percentages of total colloid, in soils of different character and from different localities.

There is a marked difference between the composition of the whole untreated soil and of the inorganic colloid suspensions obtained from it. Aside from the difference in the silica, the differences in the iron and aluminium are evidently significant, especially in the light of determinations made on a soil of different physical and mechanical properties.

A heavy adobe soil from near Whittier, Cal., was treated with different inorganic substances. Determinations of inorganic colloid suspension were made, and the colloid partially analyzed. Table X gives the results obtained.

TABLE X.—*Partial analysis of whole soil, and of inorganic colloid suspensions obtained from the same soil after having received different inorganic treatments. Heavy adobe soil, near Whitney, Cal.*

Soil treatment.	Colloid in soil.	Silicon dioxid.	Ferric oxid.	Aluminium oxid.	Calcium oxid.	Manganous oxid.	Phosphorus pentoxid.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Untreated	0.623	60.7	11.5	22.9	2.3	0.96	0.16
Calcium carbonate 3 per cent.	.558	58.8	11.0	21.7	2.4	1.44	.48
Sodium nitrate 0.2 per cent.	.803	59.1	11.9	20.7	1.8	1.57	.38
Ammonium sulphate 0.2 per cent.	.670	58.2	10.4	20.9	2.0	2.14	.25
Whole soil		60.8	3.4	14.2	4.5	.36	.08

The analysis of the inorganic colloid suspensions obtained from the adobe soil under various treatments does not indicate any fundamental differences in the composition due to these treatments.

The percentage of iron and aluminium in the colloids is markedly higher than in the original soil, the same relation as was found in the soil from Riverside (Table IX). The percentage of silica in the original adobe soil is about the same as in the colloid suspensions obtained from it.

A comparison of Table IX with Table X shows that the percentage of iron and aluminuim in the colloid suspensions obtained from the Riverside soil is higher than that in the colloid suspensions obtained from the

adobe soil. The Riverside soil is very prone to form plowsole, more so than the Whittier soil. This may be due to the higher content of iron and aluminium in the inorganic colloid suspension.

Stewart (7) suggests that the plasticity of clay is due to the presence of organic aluminium compounds. The chemical association of aluminium with organic substances in the colloid suspensions here studied has not been examined.

SUMMARY

A hard soil layer, here termed "plowsole," usually forms immediately under the soil mulch in cultivated Citrus groves in southern California. It often seriously limits the root system of the shallow-rooted Citrus trees, and seriously interferes with penetration of irrigation water. After being broken up with a subsoiler, it reforms when cultivation is resumed.

It does not form in mulched basins, nor seriously in groves surface mulched with organic matter and seldom cultivated.

Mechanical packing is not necessary for its formation, and it forms in all soil types examined in the area studied.

No greater accumulation of water-soluble iron, calcium, magnesium, or silica was found in the plowsole than in the soil mulch or subsoil.

No greater accumulation of total ammonia-soluble silica, iron, aluminium, or phosphoric acid was found in the plowsole than in the soil mulch or subsoil, after the calcium had been removed with hydrochloric acid.

The humus extract of plowsole contained more colloidal silica, iron, and aluminium than either the soil mulch or subsoil, but no more colloidal phosphoric acid.

Both the organic and inorganic colloidal material in the humus extract moved toward the positive pole in an electric current.

A conventional method for the determination of inorganic "colloid suspension" is given.

Plowsole contained a markedly higher percentage of inorganic colloid suspension than the soil mulch, and usually a higher percentage than the subsoil.

When soils were placed in pots in the laboratory, irrigated, and allowed to dry, the percentage of colloid suspension was found to be appreciably greater in the surface soil layer than in the subsurface layer, indicating that the colloids moved with the capillary soil moisture.

No relation could be observed between the percentage of inoragnic colloid suspension and the percentage of organic carbon or humus in the soil.

Native uncultivated soils contained appreciably less colloid suspension than did similar soils which had been under cultivation for a number of years.

The decomposition of 1 per cent organic matter in soil had no marked effect on the percentage of inorganic colloid suspension; 3 per cent organic matter in some cases decreased the per cent of colloids. Barley decreased the amount of colloid suspension more than did alfalfa or manure.

The addition of ground lime rock appreciably decreased the percentage of inorganic colloid suspension in the soil when no organic matter was added. When organic matter was added, the flocculating effect of lime was appreciably diminished, especially in clay loam soil.

The addition of powdered sulphur and gypsum to soil markedly decreased the colloid content, and organic matter had no appreciable effect in counteracting the flocculating effect of these substances.

The addition of sodium nitrate to soil markedly increased the colloid content, and the addition of organic matter appreciably decreased the deflocculating effect of this compound.

The addition of lime, sulphur, sodium nitrate, iron sulphate, ammonium sulphate, and organic matter to soils did not fundamentally change the composition of the inorganic colloid suspension obtained from the soil.

The addition of gypsum to soil increased the percentage of silica, calcium and manganese, and decreased the percentage of iron in the colloid suspension.

The inorganic colloid suspension contained an appreciably higher percentage of iron, aluminium, and manganese than the untreated soil.

In soils which readily form plowsole the percentage of silica in the colloid suspension was also appreciably higher than in the untreated soil.

The percentage of iron and aluminium in colloid suspensions from soils which readily form hard plowsole was higher than in colloid suspensions from soils which do not form a hard plowsole.

The percentage of iron and aluminium in the colloid suspension from a soil was found to be directly correlated with the readiness with which the soil formed plowsole.

LITERATURE CITED

(1) Ashley, Harrison Everett.
1909. THE COLLOID MATTER OF CLAY AND ITS MEASUREMENT. *In* U. S. Geol. Survey Bul. 388, 65 p., 9 fig., 1 pl. References, p. 59–62.

(2) Breazeale, J. F.
1917. FORMATION OF "BLACK ALKALI" (SODIUM CARBONATE) IN CALCAREOUS SOILS. *In* Jour. Agr. Research, v. 10, no. 11, p. 541–590, 26 fig., pl. 62 Literature cited, p. 589.

(3) ———
1917. QUALITY OF RIVERDALE IRRIGATION WATER. *In* Cal. Citrograph, v. 2. no. 4, p. 14.

(4) Fraps, G. S.
1914. AMMONIA-SOLUBLE INORGANIC SOIL COLLOIDS. Texas Agr. Exp. Sta. Bul. 165, 8 p.

(5) JENSEN, Charles A.
1917. EFFECT OF DECOMPOSING ORGANIC MATTER ON THE SOLUBILITY OF CERTAIN CONSTITUENTS OF THE SOIL. *In* Jour. Agr. Research, v. 9, no. 8, p. 253–268.

(6) MCBETH, I. G.
1917. RELATION OF TRANSFORMATION AND DISTRIBUTION OF SOIL NITROGEN TO THE NUTRITION OF CITRUS PLANTS. *In* Jour. Agr. Research, v. 9, no. 7, p. 183–252, 19 fig. Literature cited, p. 251–252.

(7) STEWART, JOHN.
1913? THE PLASTICITY OF CLAY. *In* Orig. Commun. 8th Internat. Congr. Appl. Chem. 1912, Sect. 7, p. 265–271.